Chapter 3.16
Imaging the Human Brain with Magnetoencephalography

Dimitrios Pantazis
University of Southern California, USA

Richard M. Leahy
University of Southern California, USA

ABSTRACT

Magnetoencephalography is a relatively new medical imaging modality for the monitoring and imaging of human brain function. Extracranial magnetic fields produced by the working human brain are measured by extremely sensitive superconducting sensors, called SQUIDs, enclosed in a liquid helium-filled dewar. Mathematical modeling allows the formation of images or maps of cortical neuronal currents that reveal neural electrical activity, identify cortical communication networks, and facilitate the treatment of neuronal disorders, such as epilepsy.

INTRODUCTION

Magnetoencephalography (MEG) is a noninvasive technique for measuring neuronal activity in the human brain. Electrical currents flowing through neurons generate weak magnetic fields recorded using magnetic sensors surrounding the head. The MEG method is part of a broad area of research referred to as biomagnetism, which involves studies of magnetic fields emanating from several organs of the human body, notably the brain and heart.

The temporal resolution of MEG is in the millisecond (ms) range, the timescale at which neurons communicate. Therefore, we can follow the rapid cortical activity reflecting ongoing signaling between different brain areas. This is a great advantage compared to other medical imaging modalities such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), where temporal resolution is on the order of seconds. Furthermore, unlike other methodologies that measure brain metabolism or the relatively slow hemodynamic response, MEG directly measures electrical brain activity. Electroencephalography (EEG) is a complimentary method to MEG, measuring electrical scalp

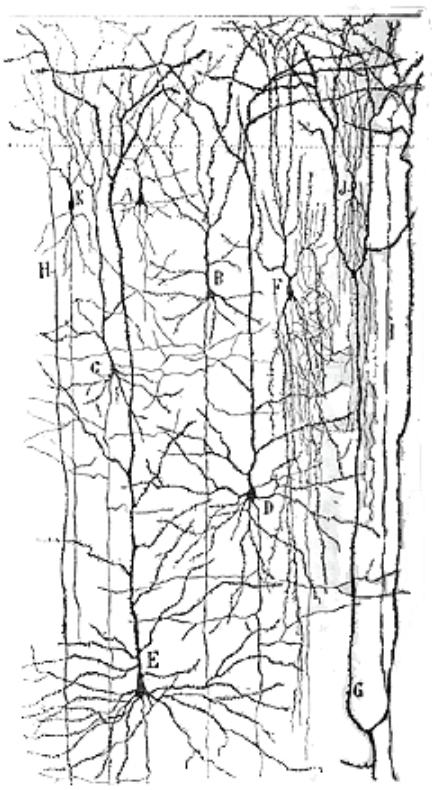
potentials rather than magnetic fields. It offers similar temporal resolution to MEG, but the spatial resolution is less accurate because electrical potentials measured on the scalp are heavily influenced by strongly inhomogeneous conductivity of the head, whereas magnetic fields are mainly produced by currents that flow in the relatively homogeneous intracranial space.

NEURAL BASIS OF ELECTROMAGNETIC SIGNALS

A neuron consists of the cell body (or soma), which contains the nucleus; branching dendrites, which receive signals from other neurons; and a projection called an axon, which conducts the nerve signal. When a pulse arrives at an axon of a presynaptic cell, neurotransmitter molecules are released from the synaptic vesicles into the synaptic cleft. These molecules bind to receptors located on target cells, opening ion channels (mostly Na^+, K^+, and Cl^-) through the membrane. The resulting flow of charge causes an electrical current along the interior of the postsynaptic cell, changing the postsynaptic potential (PSP). When an excitatory PSP reaches the firing threshold at the axon hillock, it initiates an action potential that travels along the axon with undiminished amplitude.

The conservation of electric charge dictates that intracellular currents, commonly called primary currents, give rise to extracellular currents flowing through the volume conductor. Both primary and volume currents contribute to magnetic fields outside the head; however, only locally structured arrangements of cells can achieve sufficient coherent superposition of currents as to produce measurable external fields. Clusters of thousands of synchronously activated pyramidal cortical neurons are believed to be the main generators of MEG signals (Figure 1). In particular, the currents associated with large dendritic trunks, which are locally oriented in parallel and perpendicular to the cortical surface, are believed to be the primary source of the neuromagnetic fields outside the head. In contrast, the temporal summation of currents for action potentials, which have duration of only 1 ms, is not as effective as for dendritic currents flowing in neighboring fibers, so action potentials are believed to contribute little to MEG measurements.

Figure 1. Cerebral frontal cortex drawn by Ramón y Cajal using a Golgi staining technique. Pyramidal (A, B, C, D, E) and nonpyramidal (F, K) cells are clearly depicted. Currents flowing in the dendritic trunks of pyramidal cells are believed to be the primary generators of magnetic signals outside the head.



INSTRUMENTATION

Empirical observations indicate that we observe sources on the order of 10 nA-m, and consequently,